

MEMORANDUM

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DECEMBER 1961

STUDIES OF THE PHYSICAL PROPERTIES  
THE MOON AND COMETS  
Quarterly Technical Progress Report #6.

PREPARED BY

JET PROPULSION LABORATORY  
California Institute of Technology

*The RAND Corporation*  
SANTA MONICA • CALIFORNIA

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## STUDIES OF THE PHYSICAL PROPERTIES OF THE MOON AND PLANETS

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## PREFACE

This is the sixth Quarterly Technical Progress Report on activities under The RAND Corporation contract with the Jet Propulsion Laboratory, California Institute of Technology, during the period October 1 — December 31, 1961. Under the terms of this contract, RAND conducts research studies on the physical properties of the Moon and the planets. This report is submitted in partial fulfillment of RAND's obligations under Contract N-33561 (NASw-6) with JPL. It was compiled and edited by M. H. Davis.

The form differs markedly from that of previous reports in this series. Hitherto they consisted primarily of extensive summaries of reports to be published and of preliminary notes about work in progress, whereas the present report simply presents a brief description of the quarter's activities.

The rapid communication of preliminary research results to JPL will be continued as in the past in the form of informal meetings and personal conversations. The need for documenting scientific results will be satisfied by the timely publication of reports and submission of papers for the open literature in accord with the usual RAND publication procedures.

The aim of this report, then, is to inform JPL of work performed during the past quarter and of the directions in which research is currently proceeding.

## I. INTRODUCTION

The varied activities of RAND in the general subject area of the moon and planets are categorized under four major headings as indicated below.

### LIGHT SCATTERING AND RADIATIVE TRANSFER ..... (page 2)

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- Lunar Figure and Surface

The participants in investigations in each general category are listed at the head of each major section.

## II. LIGHT SCATTERING AND RADIATIVE TRANSFER

Investigators: J. L. Carlstedt  
Diran Deirmendjian  
T. N. Divine (consultant)  
T. W. Mullikin  
Zdenek Sekera (consultant)

### Computation of the Chandrasekhar X and Y Functions

Since the computation of the X and Y functions of Chandrasekhar has not been discussed in any of the previous reports in this series, it is in order first to outline what these functions are and how they are important to the problems of planetary exploration.

An important part of the radiation received from a planet arises from multiple scattering of sunlight by the planet's atmosphere. A lysis of this scattered sunlight offers a potentially useful tool in the study of planetary atmospheres. In addition to this direct utility, understanding of the scattered component of the radiation received comprises a vital part of the theoretical background for studies of such other phenomena as ultra-violet resonant scattering, absorption in atmospheric layers (as by ozone), etc. Such studies will become increasingly important as observations of planetary atmospheres are improved by the use of balloon-borne instruments and space probes.

Zdenek Sekera has engaged for a number of years in a research program to develop the necessary mathematical techniques for studying scattering and radiative transfer in planetary atmospheres and to actually perform the calculations for certain important cases. The Chandrasekhar X and Y functions, from which the solution of the radiative-transfer equation can be readily obtained, were computed several years

ago for optical thicknesses up to unity for Rayleigh scattering in a plane-parallel atmosphere.

Recently, under JPL sponsorship, Sekera has been working on an extension of this work to optical thicknesses greater than unity. The importance of such an extension is twofold: it will provide results applicable, for visible light, to dense or extensive atmospheres such as those of the major planets, and, since Rayleigh scattering depends upon the inverse fourth power of the wavelength of the radiation, extension to larger values of optical thickness implies extension to shorter wavelengths. An optical thickness of unity corresponds in the terrestrial atmosphere to a wavelength of about 3100 Å.

It has very recently been discovered that the iterative procedure used to obtain the X and Y functions for small optical depths appears to fail for values of optical thickness greater than about 5. This difficulty has led to a recent investigation by T. W. Mullikin into the fundamental mathematical nature of the radiative-transfer problem, which has so far shown that certain uniqueness properties that had always been assumed for the X and Y functions do not, in fact, hold.

The status of the problem is that Sekera and Mullikin are continuing theoretical and computational studies that will lead to a fuller understanding of this exceedingly complex mathematical problem.

In addition, Sekera is beginning to consider the problem of scattering for moderate optical thickness with a small amount of absorption. This work will find application in the interpretation of ultraviolet scattering by the upper atmosphere of a planet.

### Radiative Transfer Heating

T. N. Divine undertook the problem of the heating of a planetary atmosphere by radiative-transfer processes. His first report, which was summarized in the fifth Quarterly Progress Report (RAND publication RM-2900-JPL), will be published in a few weeks. The new report gives in detail the mathematical theory of heating of a nonconvective atmosphere by radiative interaction with the ground, which is itself heated during the daily solar cycle.

In the last quarter, two important steps were made. (1) It has proved possible to find Elsasser-band models that fit laboratory measurements of the infrared-absorption spectrum of carbon dioxide to within about 10 per cent. About 10 Elsasser models will be used for that part of the carbon dioxide absorption spectrum which will be important for understanding the radiative heating of the Martian atmosphere. (2) The program that will be used to compute the radiative temperature distributions within the Mars atmosphere has been outlined, and FORTRAN programming is under way.

### Light Scattering by Particles and Particle Dispersions

The interpretation of scattered radiation from planetary atmospheres depends ultimately upon a knowledge of the scattering produced by the atmospheric gas, and by the individual particles and dispersions of particles that may be there. Diran Deirmendjian has been engaged for a number of years in a study (by means of the exact Mie theory) of the scattering properties of dielectric spherical particles as well as particles that have a finite conductivity. Recently, he has used this

theoretical work to investigate the scattered intensity and polarization of radiation from clouds of particles that are distributed in size.

The paper "Exact Theoretical Scattering and Polarization Properties of Polydispersed Clouds" was delivered by Deirmendjian at the Western Regional Meeting of the American Geophysical Union on December 28, 1961. A very recent result, which he reported, is that although Lyot's supposition -- that the size distribution of cloud droplets in the Venus clouds might be inferred from polarization data -- appears to be correct, the mean size derived by him may be wrong. Lyot inferred approximately a 2.5-micron diameter for the cloud particles, while Deirmendjian's work suggests that the predominant diameter is more nearly 1 micron and that the particles probably absorb visible radiation slightly. These results are highly tentative at the present time, but work is under way that may lead to more definite conclusions.

Most of Deirmendjian's research has been supported under the Air Force's Project RAND contract. However that part of his recent work which deals specifically with planetary problems was supported under the RAND contract with JPL.



### III. PLANETARY ATMOSPHERES

Investigators: M. H. Davis  
Yale Mintz (consultant)  
Carl Sagan (consultant)  
G. F. Schilling  
Peter Wegener (consultant)  
W. W. Kellogg

#### The Atmosphere of Mars

A letter to the Editor of the Journal of Geophysical Research entitled "A Note on the Atmosphere of Mars," by G. F. Schilling, is scheduled to appear in the March issue. This paper is based on the work reported in previous reports in RAND's JPL series and is a summary, on the basis of our present state of knowledge, of the limiting value for the variations of pressure, temperature, and density with altitude for the Martian atmosphere. His detailed monograph on this subject, which collects and elaborates previous results, is shortly to be published as a RAND Report entitled Limiting Model Atmospheres of Mars.

Recently, Peter Wegener undertook the problem of defining the possible flight regimes in the Mars atmosphere. He has drafted a document that compares the Mars flight regimes with those for the Earth and for Venus. This work will continue.

#### Theory of Planetary Atmospheric Circulation

During the last quarter, Yale Mintz completed his theoretical analysis of the seasonal atmospheric circulation of the planet Mars. This work is scheduled to appear as an appendix to the report on planetary atmospheres prepared for the Space Science Board of the National Academy of Sciences.

Further research in the general theory of planetary circulation will be directed toward (1) an investigation of the circulation of the atmospheres of Mars, including nonlinear terms, after such investigation has been completed for the Earth; and (2) attempts to verify the theory by application (using the high-speed computers) to situations that have been investigated in the laboratory, such as the "rotating dishpan" technique. Only those parts of this work which apply to planetary circulation per se are supported by JPL; the remainder is supported by Mintz's UCLA research program.

#### Planetary Atmospheres -- General

During the past quarter, W. W. Kellogg and Carl Sagan completed their summation of the status of current knowledge of the atmospheres of Mars and Venus. This material will be published as a chapter in the report on planetary atmospheres referred to above.

Sagan, using some new cosmic-ray data, has also revised his RAND publication RM-2832-JPL, Is the Martian Blue Haze Produced by Solar Protons? The conclusions are substantially unchanged from the original report. He presented the new paper at the December 1961 meeting of the American Astronomical Society in Denver and has submitted it for inclusion in the first issue of the new journal Icarus.

#### IV. PLANETARY EXPERIMENTS

Investigators: M. H. Davis  
S. M. Greenfield  
H. L. Weisberg (consultant)

##### Stellar Occultation

The report by H. L. Weisberg that was summarized in the fifth Quarterly Technical Progress Report (RAND publication RM-2900-JPL) is being revised. Another line of planetary-experiment planning recently undertaken is described in the following paragraphs.

##### The Mars Balloon

Any program of unmanned exploration of a planet carries with it the connotation of ultimately moving the exploring instruments about the surface of the planet. To date, all such plans have considered mobile vehicles that walked or crawled or rolled over the surface.

S. M. Greenfield and M. H. Davis are investigating an entirely different concept -- the use of a balloon to provide the desired mobility on the planet.

Assuming that a mother capsule will land on the planet and subsequently release an instrumented balloon, some questions that require answering are these:

1. What payloads may be carried at useful heights for significant distances, and what total load must be carried to the surface of the planet to accomplish this?
2. To what accuracy can the position of the mother capsule and the relative positions between the capsule and the balloon be determined?

3. What useful observations and combinations of observations can be made by the combined system of instruments in the mother capsule and in the balloon?

Setting up the standard hydrostatic balance equation for a balloon system, and utilizing Schilling's minimum, mean, and maximum values for the Martian atmosphere (RAND publication RM-2782-JPL), it is possible to determine what payloads the balloon could carry at various specified altitudes. For example, take the following specifications and assumptions:

1. A floating altitude of 10 km above the Martian surface is desired.
2. The most pessimistic of Schilling's values (the most rarified atmosphere) is assumed to be the true one.
3. A polyethylene balloon 5 meters in diameter is used.
4. Hydrogen is specified as the lifting gas.

Under these conditions the balloon mass is about 4.4 kg; about 1.7 kg of hydrogen gas is required; and the instrument payload that this combination will support is about 15 kg. This balloon system, with no supplementary ballasting device, should float for 12—24 hours at 10 km (at 20 km if Schilling's other extreme model is correct). If a container for the gas, either in pressurized or liquid form, is included, the total mass that must be transported to Mars for the balloon system alone (not including its payload) is of the order of 20 kg. It should be remarked that the engineering details of how best to transport the hydrogen and then fill the balloon have not yet been worked out.

Preliminary calculations suggest that, with a minimum of three precisely timed determinations of the sun's elevation angle from the local vertical, it will be feasible to fix the position of the mother capsule in latitude and longitude and the position of the balloon relative to the capsule. An error analysis of this position-determination method is presently under way.

The balloon system would be useful in furthering knowledge in either of two general subject areas. Measurements taken as the balloon drifts above the surface of Mars could contribute to the knowledge of the atmosphere (its circulation, temperature, pressure, composition, and the like). On the other hand, if knowledge of the particulars of the planetary surface were the principal objective, a balloon could be the means of transporting suitable instruments from the point of landing to another area — say one of contrasting characteristics.

## V. LUNAR AND PLANETARY GEOLOGY AND MAGNETIC FIELDS

Investigators: K. J. Buettner (consultant)  
J. W. Kern  
D. L. Lamar

### Figures of the Planets

D. L. Lamar presented a paper at the American Geophysical Union's meeting at UCLA, December 28, 1961, entitled "Optical Ellipticity and Internal Structure of Mars." This paper was based on work which was summarized in its preliminary form as Chap. VIII of the fifth Quarterly Technical Progress Report. Lamar has also completed work on his paper "Note on the Age of the Earth-Moon System," which appeared in preliminary form in the fifth quarterly. This paper will soon be submitted to a journal for open publication. Using his work on the figure of Mars as a point of departure, Lamar in collaboration with J. W. Kern, has nearly completed a study of the rate at which the axis of rotation of terrestrial planets can move relative to the crust of the planet. For the Earth, they find that (according to their theory) the upper limit is  $3 \times 10^{-7}$  to  $2 \times 10^{-10}$  radians per year (2 m/yr or less) where the motion is retarded not by a finite strength in the mantle, but rather by dynamical forces that arise from the figure of the phase-change boundary in olivine several hundred km deep within the upper mantle.

### Magnetic Fields of the Planets

Another line of planetary geophysical research recently undertaken by Kern concerns the strength of the magnetic fields of Mars and Venus. If the hydromagnetic dynamo theory is correct, and a planet has a core like that of the Earth, the resulting magnetic field should scale

directly with the rotation rate. However, if the planet is different from the Earth in internal structure, as Mars may be, such a simple scaling will probably not apply. It is planned that a memorandum on this subject be written when the work is complete.

#### Lunar Figure and Surface

Lamar is currently undertaking a harmonic analysis of the lunar topography. He believes that it will be possible to draw inferences about the distribution of density and the internal structure of the Moon from the relationships between the low harmonics of the topography as determined by harmonic analysis and the moments of inertia determined from astronomical observations.

K. J. Buettner is preparing a paper in which he reviews and evaluates the data from thermal observations of the lunar surface. One conclusion he draws is that the data are far more inaccurate than had been supposed by most authorities in the past and that no unique inference drawn from thermal and radio measurements is possible at present concerning the nature of the lunar surface material.